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# Reply to "Comment on 'Revisiting the 1872 Owens Valley, California, Earthquake' by Susan E. Hough and Kate Hutton" by William H. Bakun

by Susan E. Hough and Kate Hutton

Bakun (2009) argues that the conclusions of Hough and Hutton (2008) are wrong because the study failed to take into account the Sierra Nevada attenuation model of Bakun (2006). In particular, Bakun (2009) argues that propagation effects can explain the relatively high intensities generated by the 1872 Owens Valley earthquake. Using an intensity attenuation model that attempts to account for attenuation through the Sierra Nevada, Bakun (2006) infers the magnitude estimate ($M_w$ 7.4–7.5) that is currently accepted by National Earthquake Information Center (NEIC).

We do acknowledge and apologize for one error in Hough and Hutton (2008): the manuscript was not, as the acknowledgments state, reviewed by Bakun prior to or after submission. The acknowledgments should have thanked Bakun for helpful discussions about the inversion approach and for providing the inversion code. We were also remiss in not thanking Nancy King, who did review the manuscript.

Before considering the issues raised by Bakun (2009), one needs to first examine the intensity values on which Bakun (2006) and Hough and Hutton (2008) (hereinafter B06 and HH08, respectively) are based, as any analysis of macroseismic data will rest critically on the quantity and quality of intensity assignments. As many authors have pointed out, intensity values are not data but rather interpretations, and any number of issues can be lurking within these interpretations. If these issues are not considered carefully, results can be significantly biased (e.g., Hough *et al.*, 2000). In their investigation, HH08 revisit all known accounts of the 1872 earthquake, including those from the extensive archival search of Toppozada *et al.* (1981), as well as a few additional accounts unearthed by their own archival research. Accounts were analyzed with careful consideration of historical building styles, as well as with insights gleaned from macroseismic observations of large earthquakes in recent times. No intensities were assigned to accounts that describe only effects, for example, rockfalls, which are known to be unreliable indicators of intensity (e.g., Hough and Elliott, 2004). This reinterpretation yielded 142 intensity assignments, presented in the electronic supplement to HH08.

In contrast, it is not entirely clear which, or how many, intensity values were used by B06. Bakun (2009) states that B06 omits modified Mercalli intensity (MMI) assignments from Toppozada *et al.* (1981) that were based on unreliable intensity indicators, but this is neither mentioned nor explained by B06. B06 do explain that all intensity assignments of V and below are discarded, arguing that the observations are not complete.

The notion that fewer intensity values are better than more intensity values for constraining magnitude is, we suggest, a curious one. On the other hand, presumably it goes without saying that, in any scientific analysis, good data (or good intensity values) are better than bad data. B06 defends the decision to truncate MMI values at V by pointing out the MMI V values assigned by Toppozada *et al.* (1981) extend to the California coastline from San Francisco to San Diego, so "the truncation of MMI V values at the California coast would bias estimates of $M_i$ if the MMI V assignments in California were concluded." As shown by HH08, the intensity distributions of the 1872 and 1906 earthquakes diverge most notably at regional distances, in part because of the well-established difficulty in distinguishing high (MMI > VIII) values for historical earthquakes. A comparison of the two events therefore hinges most critically on the intensity distribution at regional distances.

The (unknown) number of intensity values that are analyzed by B06 are apparently taken directly from Toppozada *et al.* (1981), without critical examination or any attempt at reinterpretation beyond (apparently) omitting values based solely on unreliable indicators. This alone renders any conclusions about magnitude suspect, as HH08 show that a careful consideration of original accounts results in significant revisions to the MMI assignments of Toppozada *et al.* (1981). The conclusion reached by Bakun (2006) that "there are almost no MMI < V assignments because most people were asleep when the 2:30 a.m. event occurred" is simply wrong. There are no MMI < V assignments in the assessment of Toppozada *et al.* (1981) because the interpretation of accounts in this study followed practices that are now recognized to be flawed. Again, considering original accounts carefully, one finds that any number of accounts specify whether "few," "many," "most," or "all" were awakened, a key distinction between MMI II–IV for earthquakes at night. Furthermore, while Toppozada *et al.* (1981) assigned MMI V for locations where "many" or "most" sleepers were awakened, if one looks to intensities determined from the

"Did You Feel It" algorithm (Wald *et al.*, 1999), it is clear that, at regional distances, MMI III–IV shaking from large earthquakes will awaken most if not all sleepers. Intensity values between II and V can thus be described based on careful consideration of perceived shaking intensity as well as other objective indicators.

In addition to revising the MMI V assignments of Toppozada *et al.* (1981), HH08 revise most of the MMI > V assignments as well. As Bakun (2009) notes, HH08 discount reports of ground failures, groundwater changes, and some other effects often used as indicators of high intensity. This is in keeping with recent results (e.g., Ambraseys and Bilham, 2003) that demonstrate that secondary effects are not reliable indicators of overall shaking intensity.

As shown by figure 5a of HH08, the difference between MMI values for the 1872 versus the 1906 earthquake is most significant at regional (> 200 km) distances. The difference between the intensity distributions for the 1872 and 1906 earthquakes is, HH08 conclude, a robust observation. The observation derives support from not only innumerous individual accounts and the careful recent analysis of Boatwright and Bundock (2005) but also G. K. Gilbert's summary observation that "at 200 miles, [the 1906 earthquake] was perceived by only a few persons" (Gilbert, 1907). In contrast, the 1872 earthquake, as noted by B06, awakened many or most sleepers along the California coast from San Francisco to San Diego.

The issue of point-source versus extended-source models is relevant for the analysis of B06 but not for HH08 because the latter study does not use the method of Bakun and Wentworth (1997) to infer magnitude but rather focuses on a direct comparison of the intensity distributions of the 1872 and 1906 earthquakes.

One can now consider the question, can the difference in these two intensity distributions be explained by propagation effects, as Bakun (2009) contends? As HH08 discuss, propagation effects could conceivably account for the relatively high intensities of the 1872 earthquake. The key question is, do we have a compelling basis for this interpretation? Bakun (2006) does determine a separate Sierra Nevada attenuation model with lower attenuation than inferred for the Basin and Range. However, the Sierra Nevada model is constrained by observations from a total of five earthquakes that occurred at the western edge of the Basin and Range, four events in the Mammoth Lakes region and one significantly north, near Truckee. Here again the intensity values themselves are discussed only in a cursory way, apparently also taken without careful review from previously published studies. Setting this (potentially significant) issue aside, the sum and total of the basis for lower Sierra Nevada attenuation are the intensity values shown in figure 9 of B06. Looking carefully at this figure, a first observation is that the distinction between the Sierra Nevada and the Basin and Range paths is subjectively determined. Average intensities between 145° and 330° are only slightly elevated for the one event near Truckee. Looking at the four Mammoth Lakes events, we suggest that an equally plausible (subjective) interpretation is that MMI values are systematically elevated not uniformly between 145° and 330° but rather for azimuths near 145° and 300°—along the strike of the Sierra front. Focusing of *Lg* waves by large-scale topography has been inferred by observational studies (e.g., Hough *et al.*, 1989) and has derived a measure of support from modeling studies as well (e.g., Kennett, 1986).

In any case, we conclude that analysis of intensity values from a total of five earthquakes, when there is good reason to suspect that the intensity values are problematic, does not constitute compelling evidence for significant intensity attenuation differences within California. We thus return to the conclusion reached by HH08: "[it is] plausible but unlikely that propagation effects can account for the relatively high intensities generated by OV1872," noting the word "plausible." Were significant intensity attenuation differences to be inferred by a systematic, careful analysis of instrumentally recorded earthquakes, or from systematic analysis of "Did You Feel It?" (Wald *et al.*, 1999) intensities, this would be grounds to reconsider the preferred magnitude estimate of HH08.

We emphasize in closing that inferences drawn about key historic earthquakes are, again, only as good as the intensity assignments on which they are based. Any number of recent studies (e.g., Atkinson and Wald, 2006; Hauksson *et al.*, 2008) have shown that intensities can provide an extremely reliable and useful indication of ground motions. Intensity assignments for historical earthquakes cannot, of course, rival the reliability of those determined by the "Did You Feel It" algorithm, which can be constrained by hundreds or even thousands of accounts. However, studies have also shown that, when original sources are interpreted carefully, with careful consideration of local construction and other factors, intensity distributions of historical earthquakes can yield detailed, reliable indications of ground motions (e.g., Ambraseys and Bilham, 2003). On the other hand, no degree of rigor or sophistication in analysis methodology will produce reliable results if they are based on significantly flawed intensity values, as is all too likely to be the case if published intensity values are analyzed without careful consideration.

## Data and Resources

All data used in this article, as well as Hough and Hutton (2008), came from published sources listed in the references and were included as an electronic supplement to Hough and Hutton (2008).

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